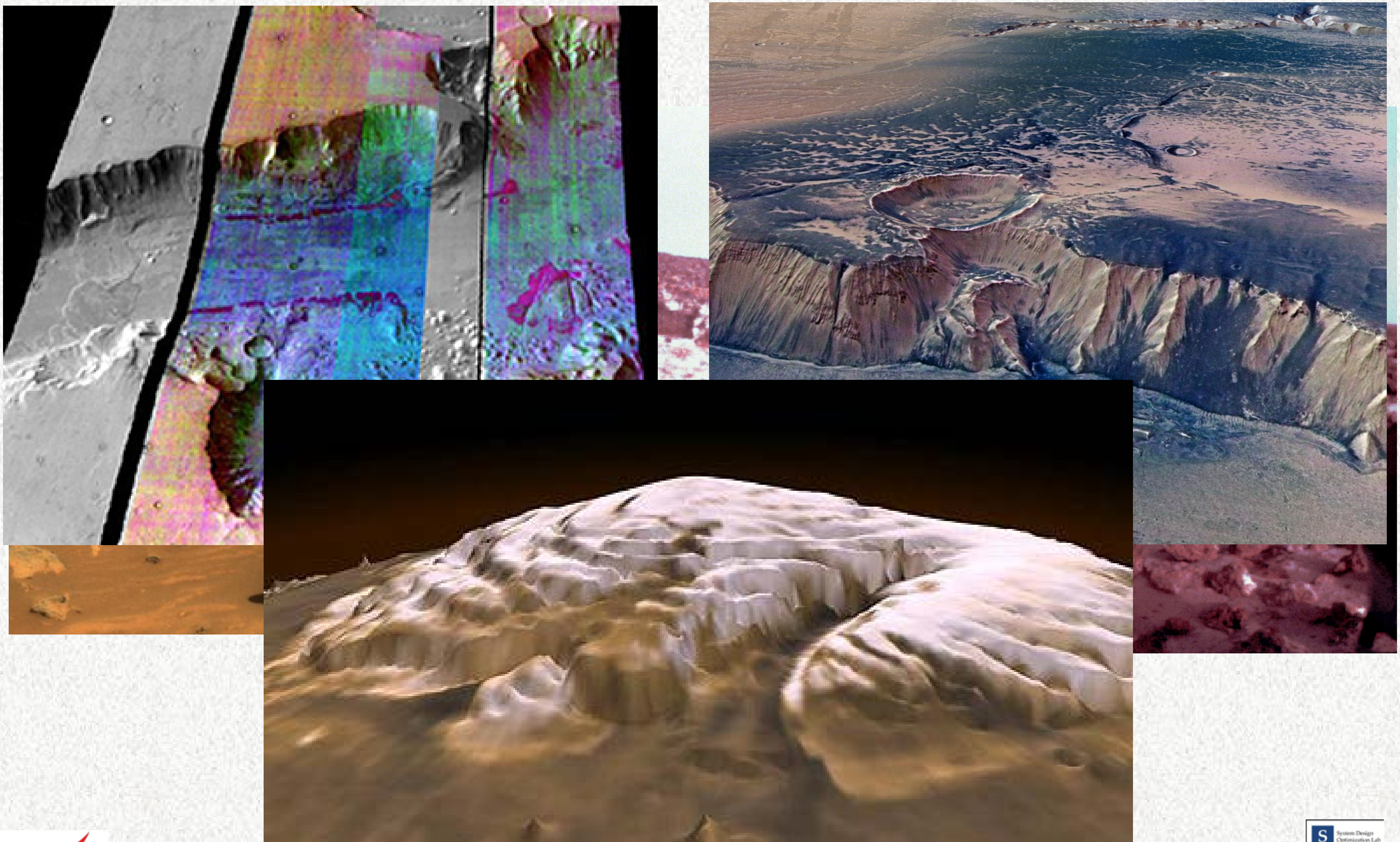
Enabling All-Access Mobility for Planetary Exploration Vehicles via Transformative Reconfiguration

Scott Ferguson
Andre Mazzoleni
3 graduate students
19 undergraduate students
Mechanical and Aerospace Engineering
North Carolina State University

We thank NIAC for their support of this work

Challenges of chaotic terrain



Is mobility enough?

How can we encourage concepts that are even more different?

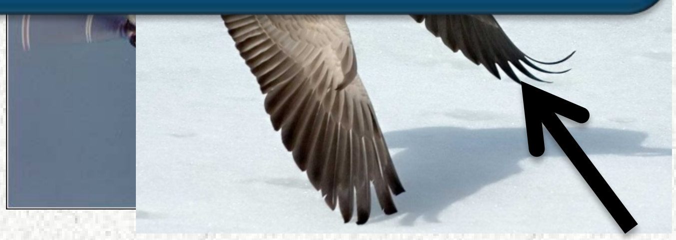
What potential advantages / mission types could we then do?

Four drivers of reconfigurability

Expand / Collapse

Expose / Cover

Multi-ability



Reorientation

Fuse / Divide

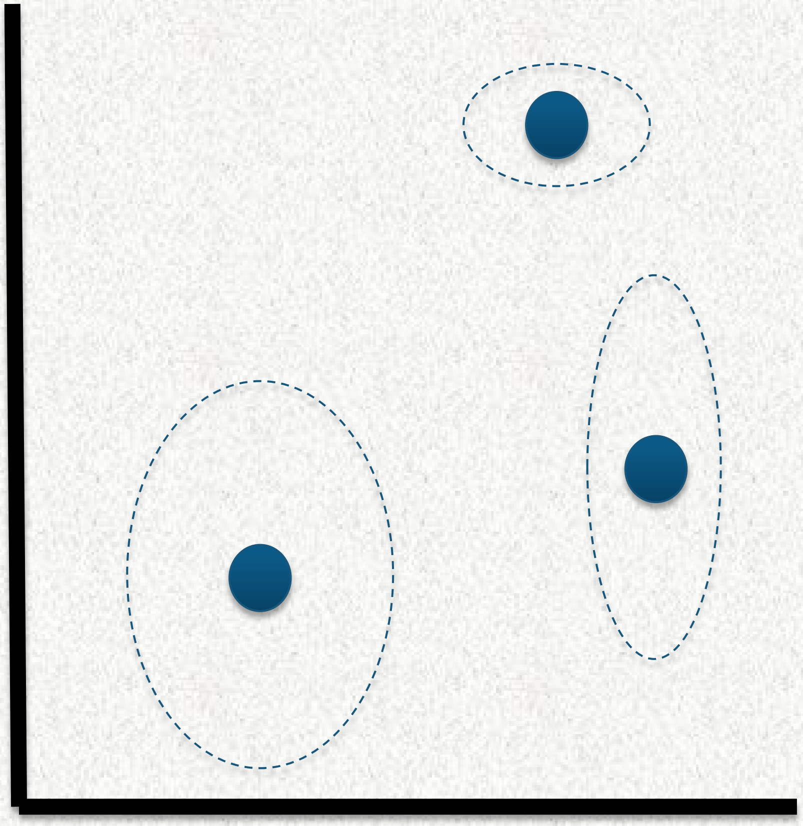
The need to constrain reconfigurability

Project objective

Multiple scientists wanting to:
- **Sense something**
- **Measure something**
- **Explore something**

Engineers want something:
- **Low risk**
- **Easily analyzable**
- **Realizable**

Project objective



What makes for an effective configuration??

Leveraging the university infrastructure

3 Graduate students (Mars exploration class)

19 Undergraduate students (Capstone design)

Identify mission, science, and requirements

Develop conceptual solutions

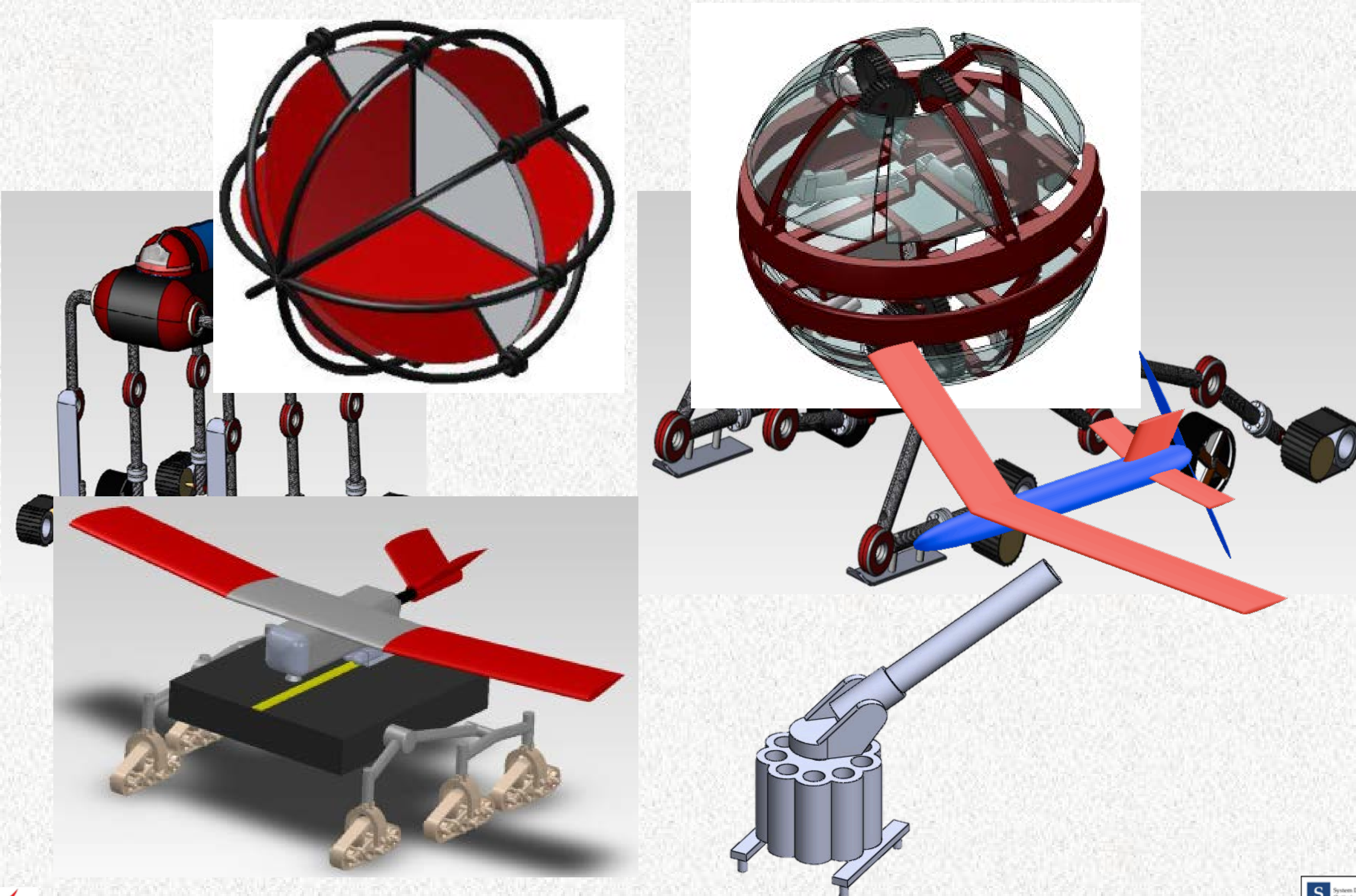
Conduct analysis

Initial prototyping

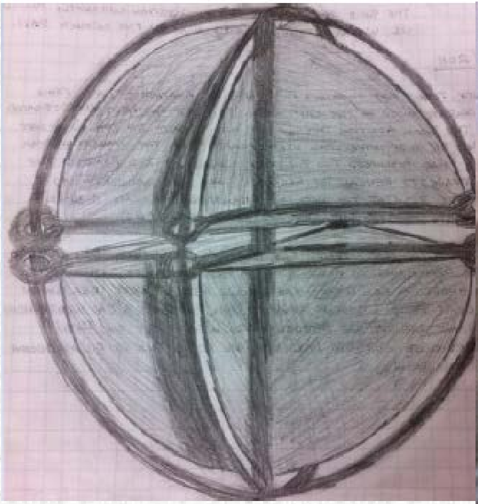
Tradespace exploration

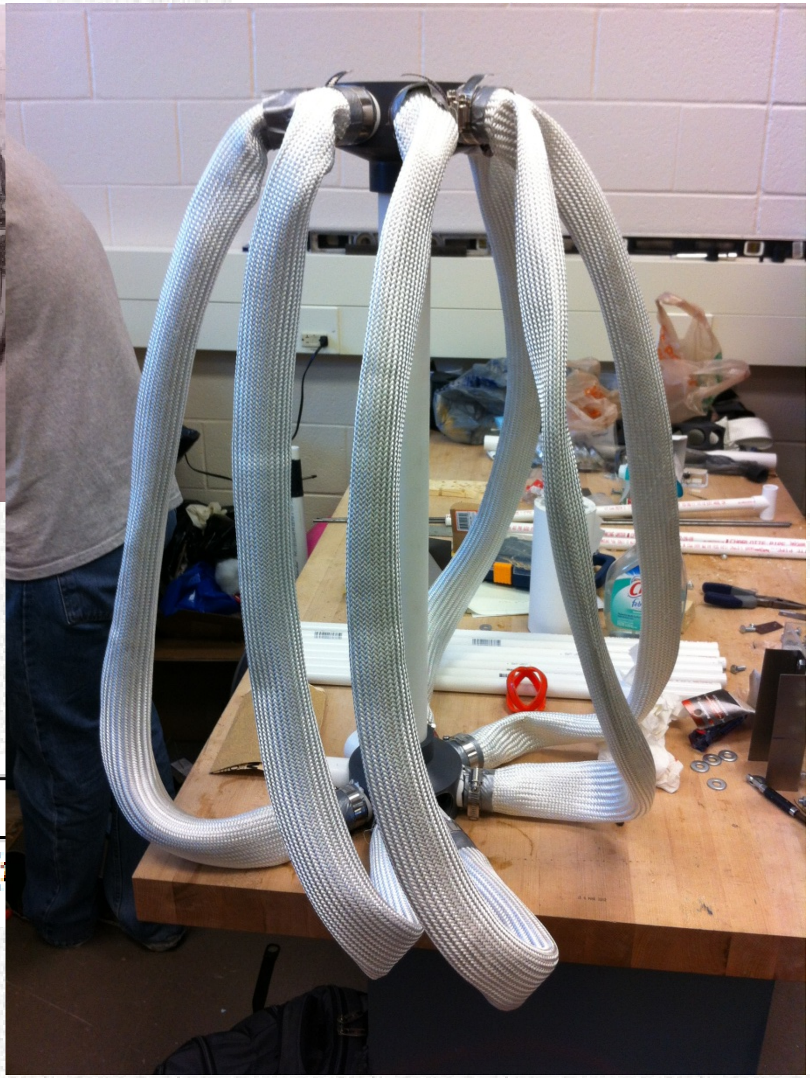
Advanced simulation

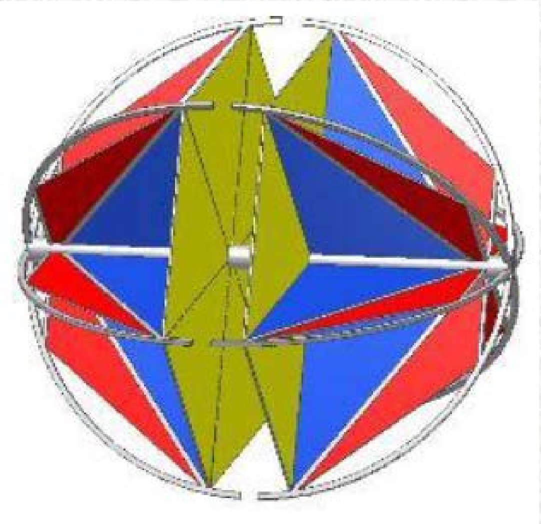
What baselines have been created so far?

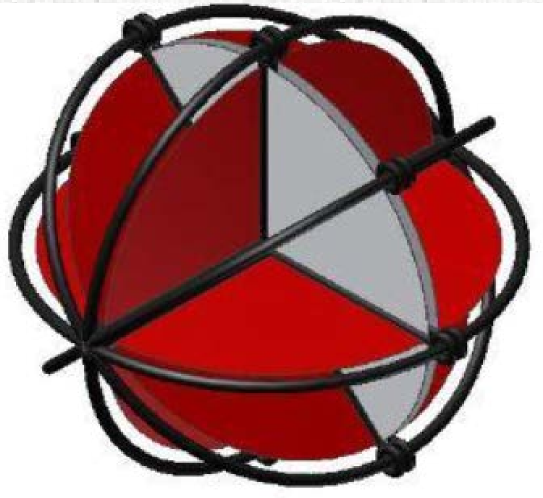


Development of the tumbleweed rover



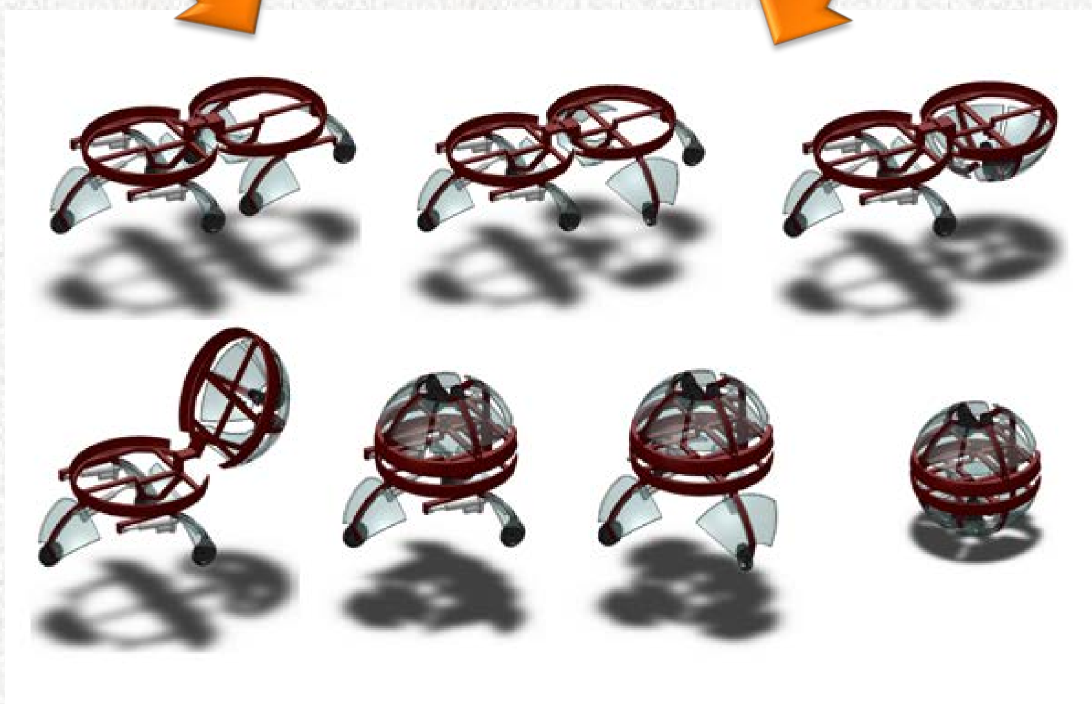






$$h_{max} = r\{1 - \sqrt{[C_D(}$$

Inspiration for the TRRex

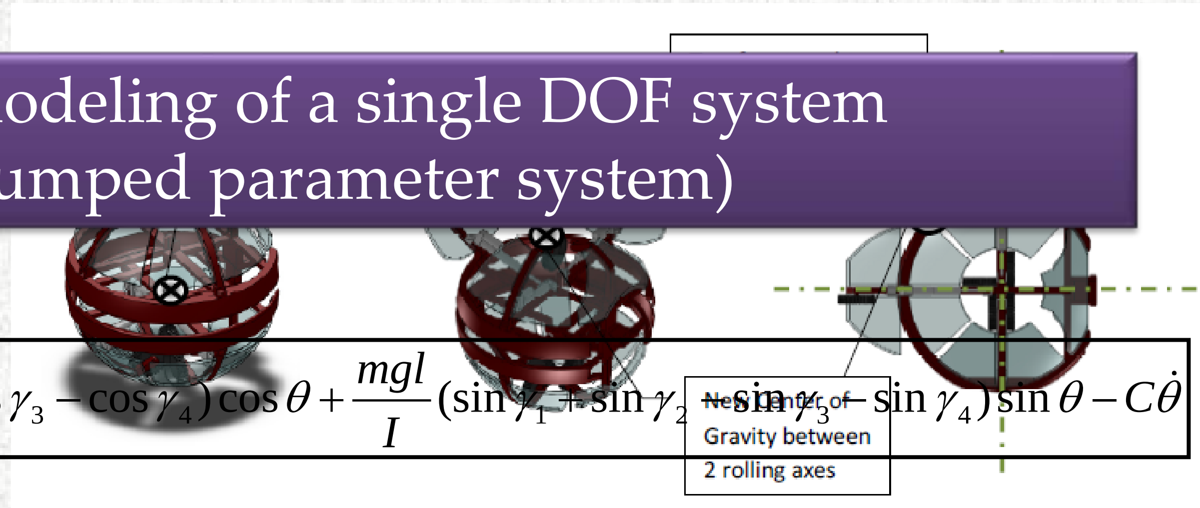


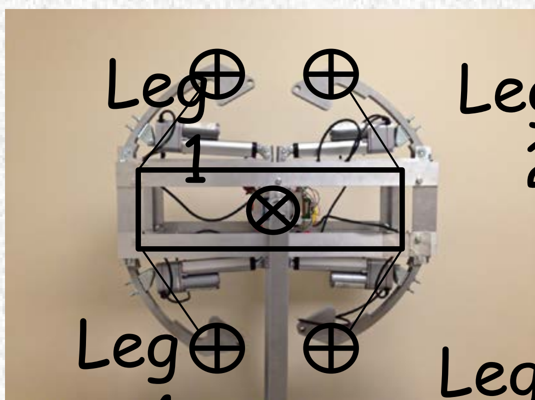
Modeling / analysis of rolling motion

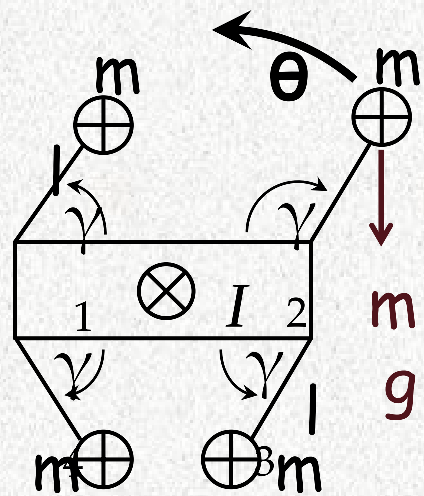
Dynamic modeling of a single DOF system (as a lumped parameter system)

us rolling in the presence of a gradient

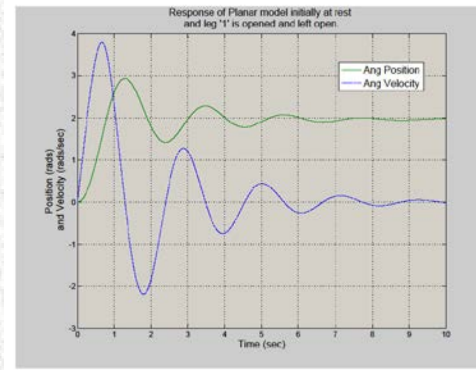
$$\ddot{\theta} = \frac{mgl}{I}(-\cos\gamma_1 + \cos\gamma_2 + \cos\gamma_3 - \cos\gamma_4)\cos\theta + \frac{mgl}{I}(\sin\gamma_1 + \sin\gamma_2 - \sin\gamma_3 - \sin\gamma_4)\sin\theta - C\dot{\theta}$$

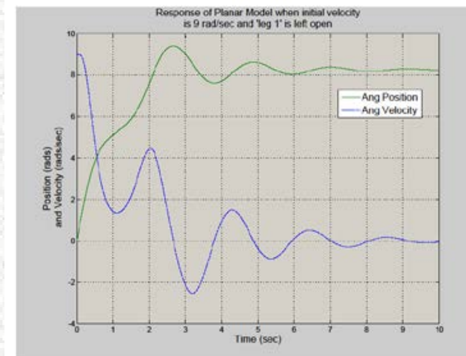


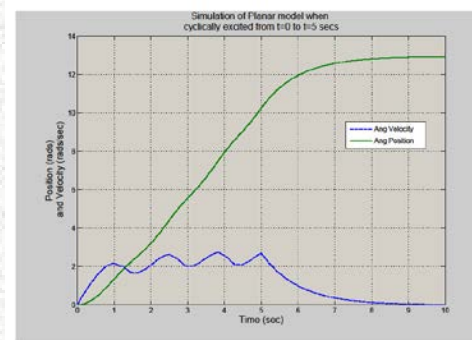




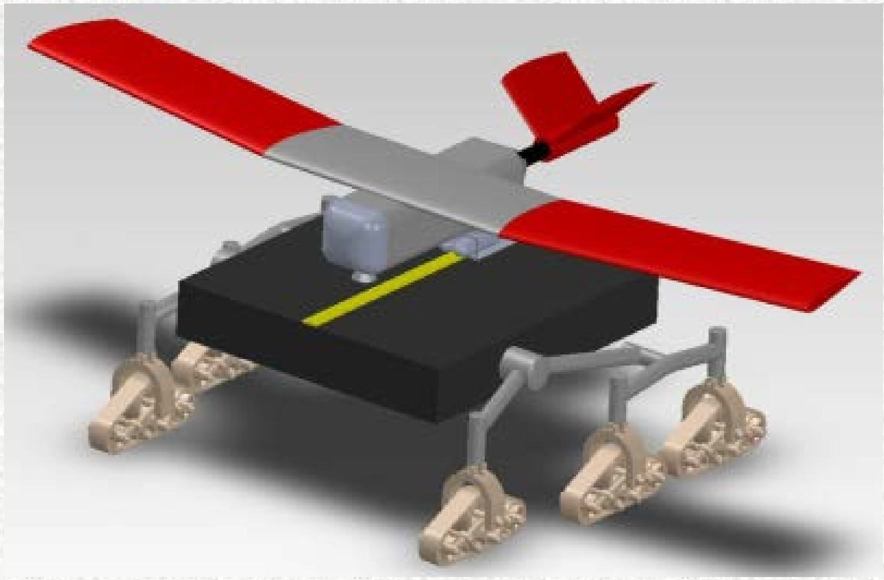
Prototype and testing

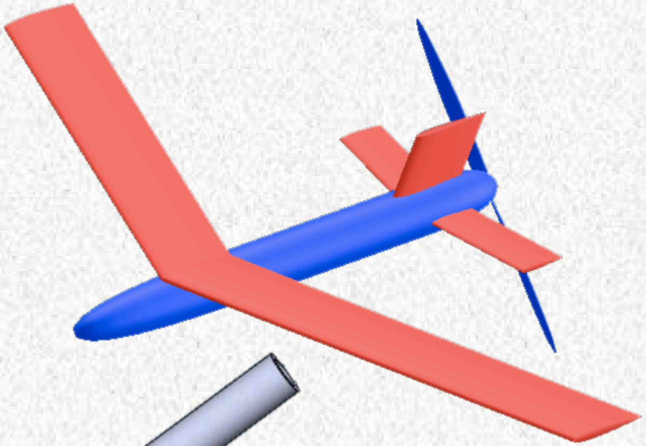


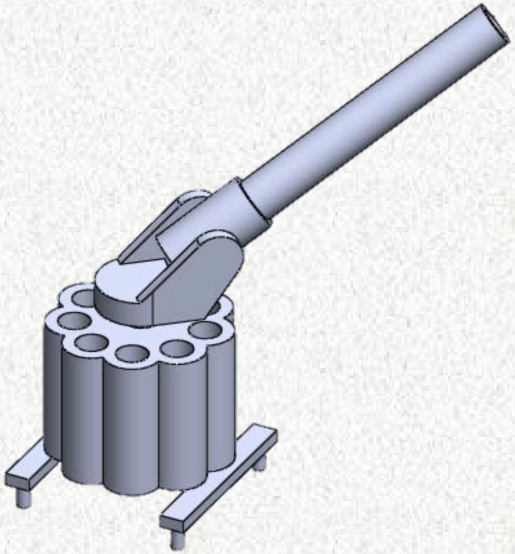




Air-based concepts







Melas Chasma

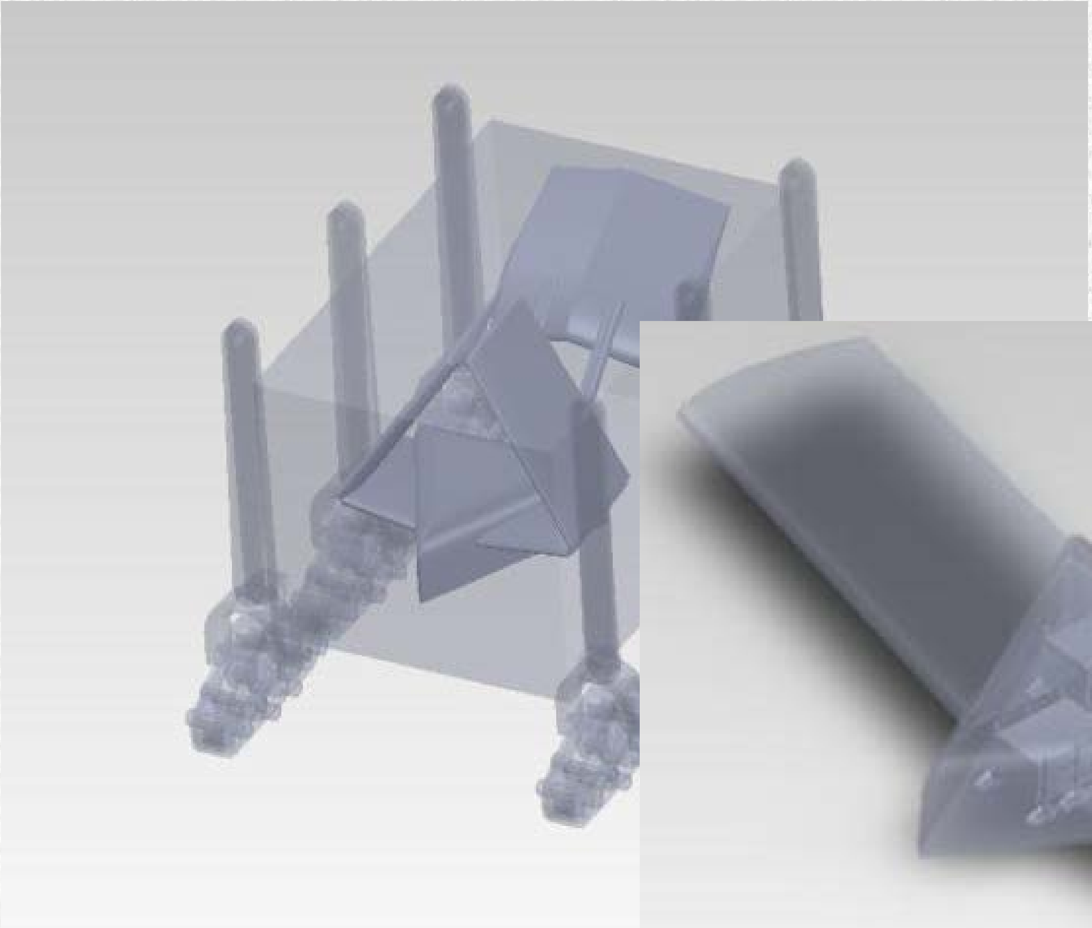
Terrain:

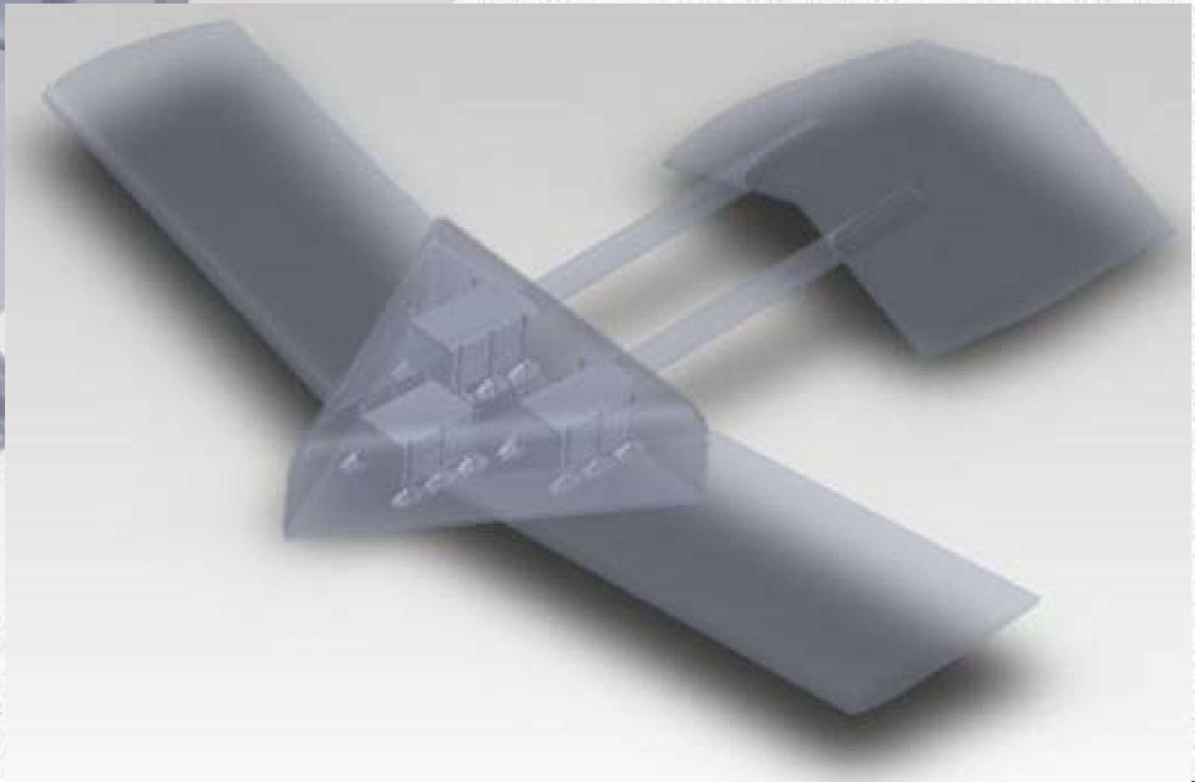
- Sand dunes leading up to, surrounding, and inside the chasm
- Rocky cliff faces 40°+ incline; landslide material 30-45° incline
- Descent of 11km
- Rocky floor and roaming sand dunes

The mission:

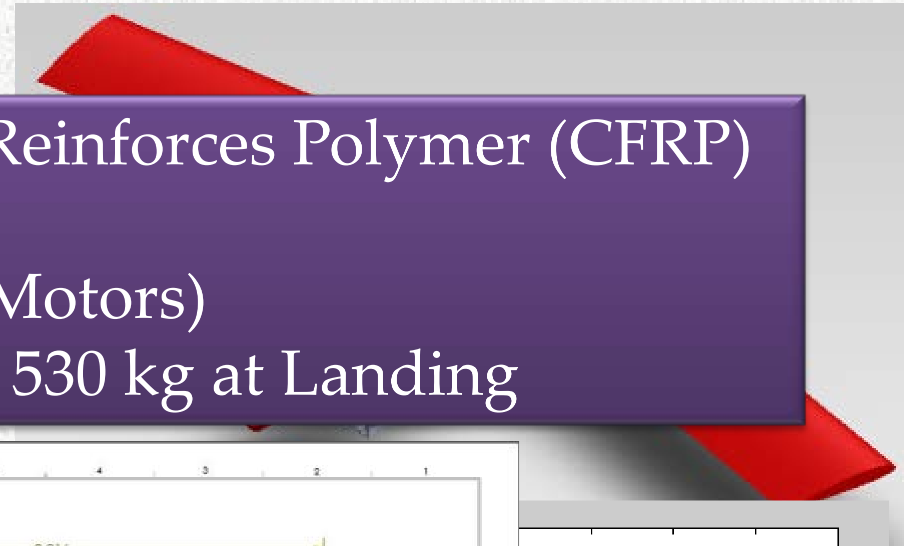
Find the most efficient way to land on the surrounding planes, traverse the dunes to reach the top of the chasm, and then descend to the floor while still being mobile once on the floor

Initial concept

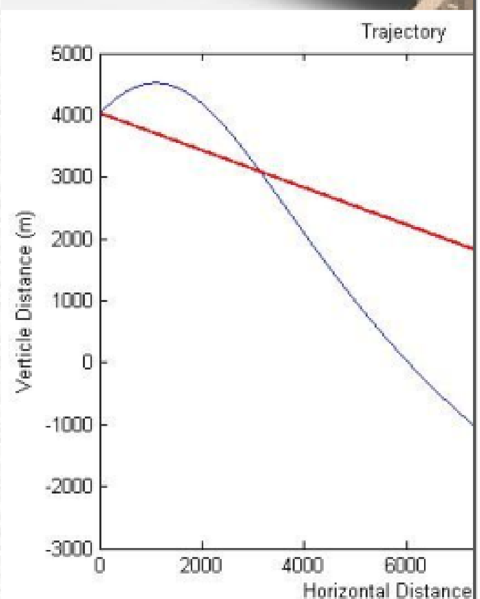


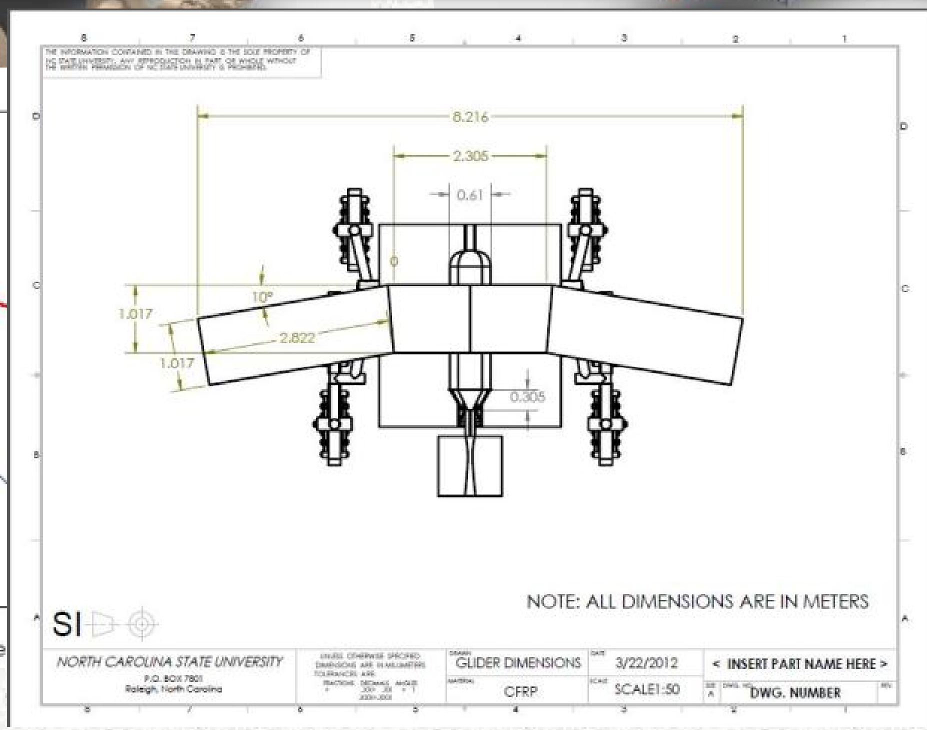


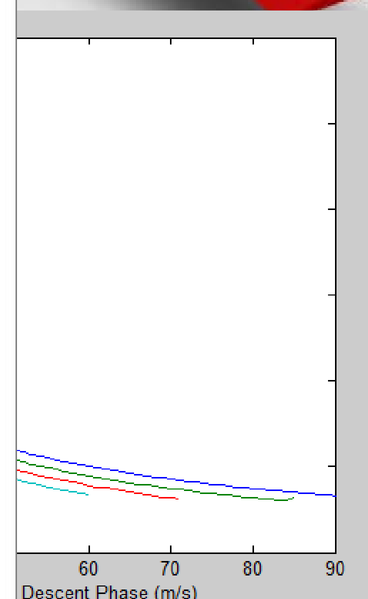
Designing the glider



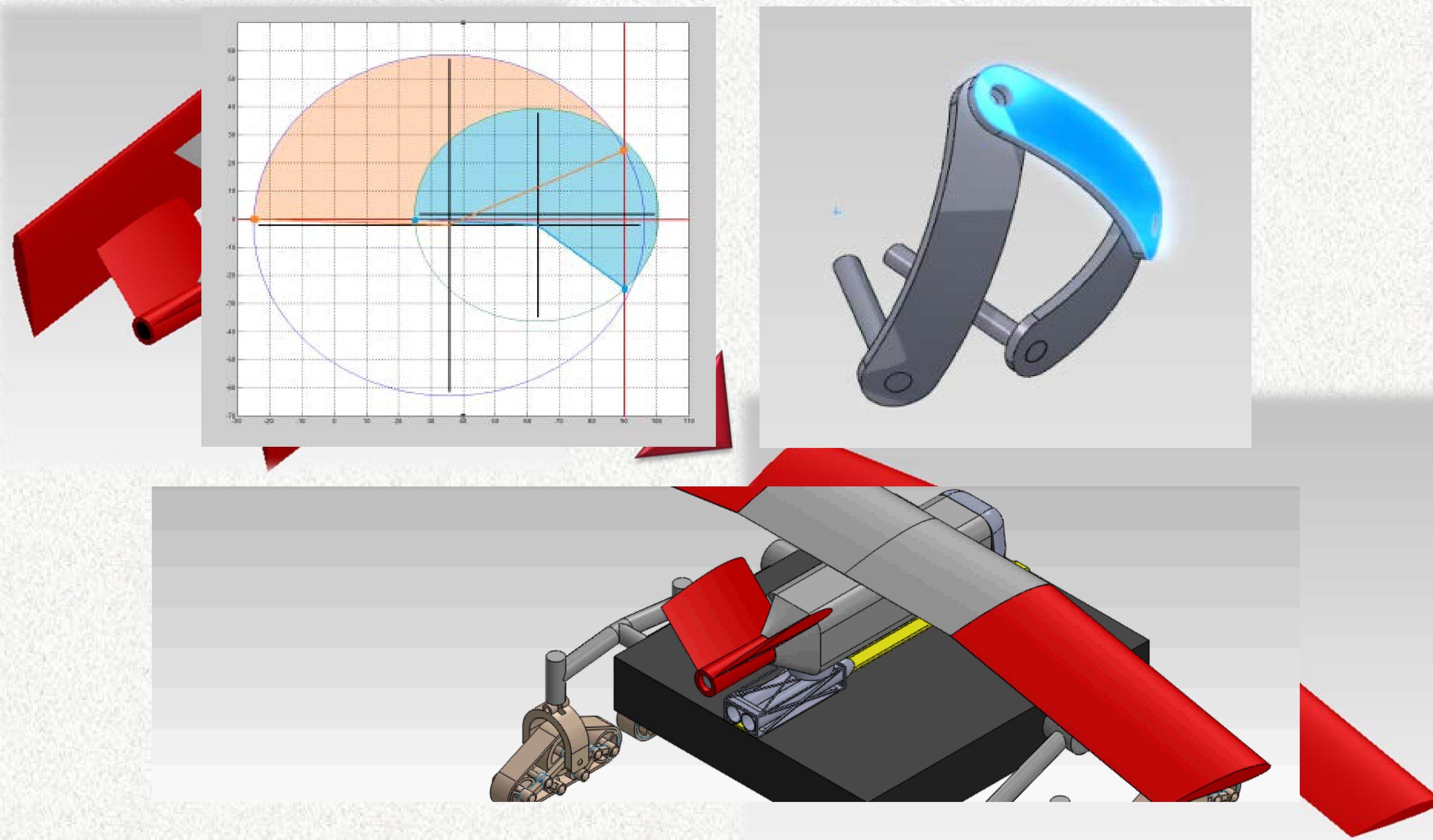
Material: Carbon Fiber Reinforces Polymer (CFRP)
Stall Speed: 100 m/s
Rocket Propellant (2 O-Motors)
Mass: 900 kg at Launch, 530 kg at Landing



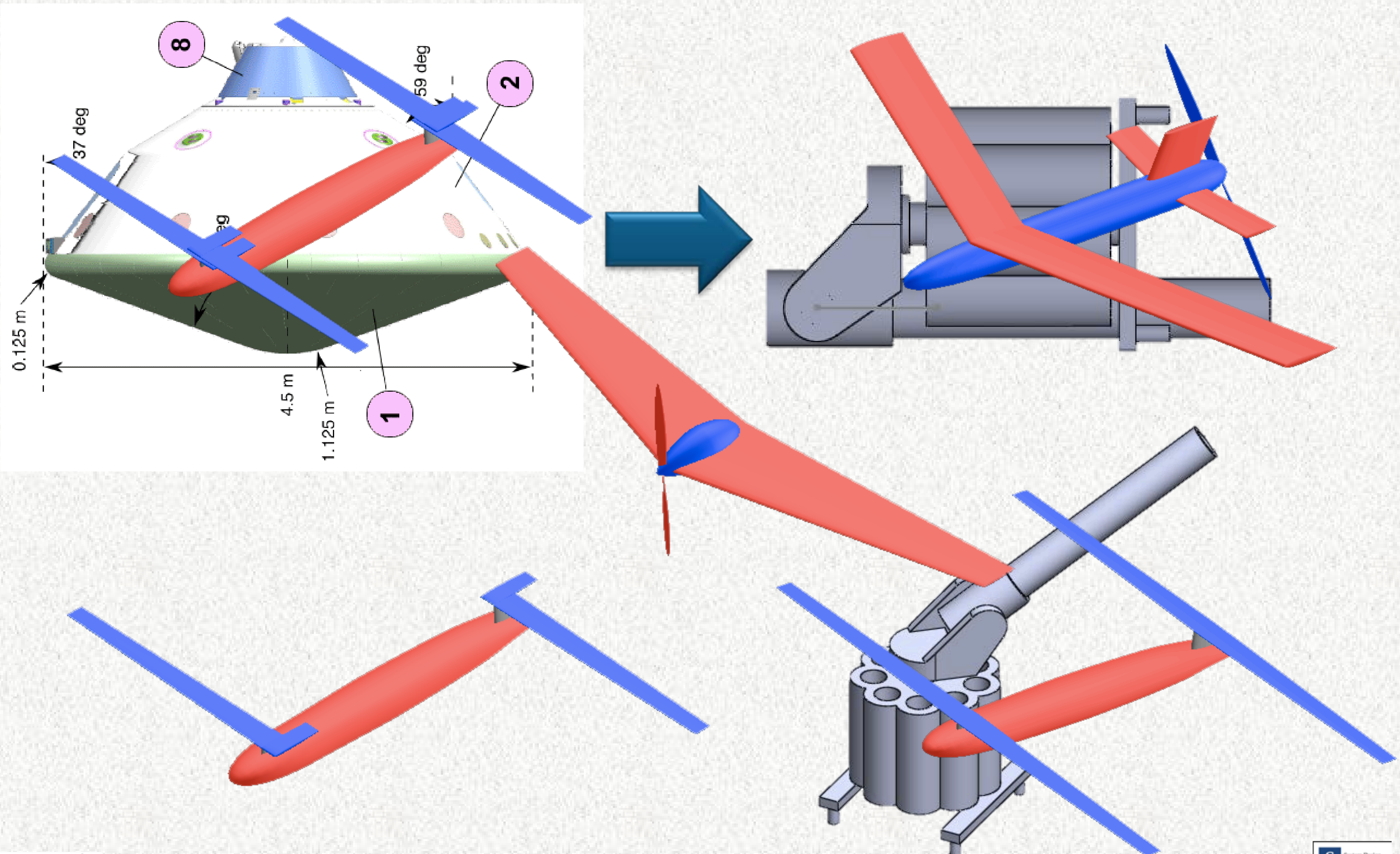




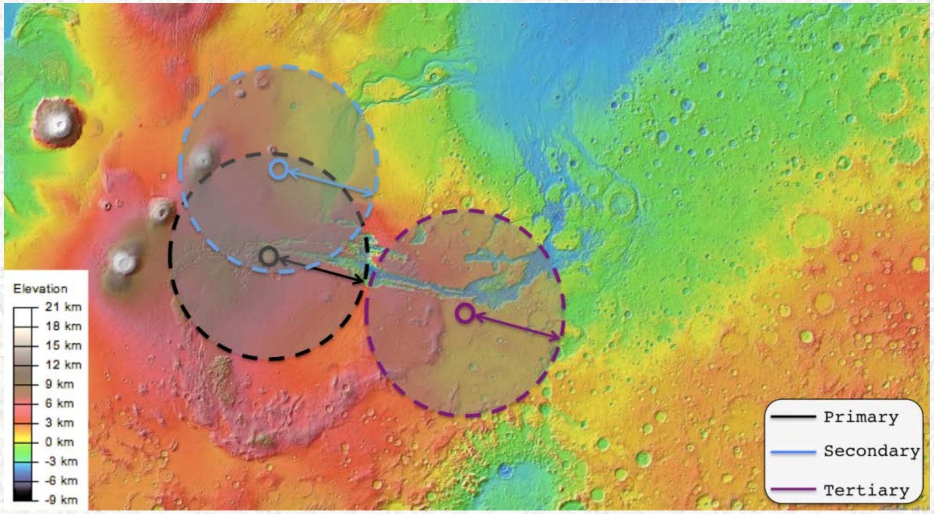
Describing the reconfigurations



Development of an air cannon



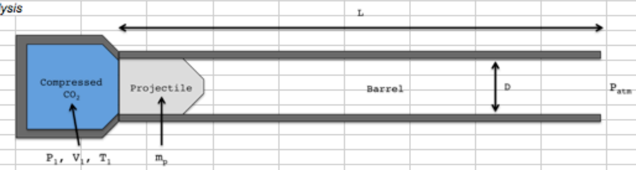
Requirements definition and analysis



Motion of a Projectile Within A Barrel

Thermodynamic Closed System Analysis

mp =	15.00	kg
L =	3.00	m
D =	0.25	m
P1 =	8000.00	kPa
V1 =	4.00E+00	m^3
T1 =	300.15	K
Tc (CO2) =	304.19	K
Pc (CO2) =	7380.00	kPa
R_u =	8.31	J/mol-K
Patm =	1.16	kPa
MWco2 =	44.01	g/mol
A =	0.05	m^2
V2 =	4.15	m^3
P2 =	7.72E+03	kPa
TR1 =	0.99	--
PR1 =	1.08	--
Z1 =	1.00	--
TR2 =	0.99	--
PR2 =	1.05E+00	--
Z2 =	1.00	--
n =	1.28E+04	# moles
mCO2 =	5.64E+05	g
Wp =	1156929.08	J
Wsurr =	170.09	J
Wnet =	-1156759.00	J
v_exit =	392.73	m/s



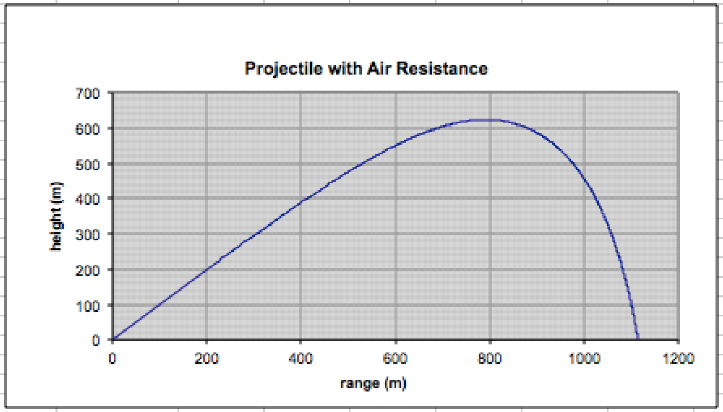
ASSUMPTIONS:
- Quasi-Equilibrium Process
- Gas behaves like and Ideal Gas (from compressibiliy EOS)
- Gas expands isothermally
- No heat exchanged
- No change in internal energy
- Neglect change in PE

Motion of a Projectile Under Gravity with Air Resistance

Projectile fired at speed v at angle theta degrees to horizontal
Air resistance = kv^2.

v =	392.73	m/s	
theta =	45.00	degrees	slider
g =	3.71	m/s^2	
delta_t =	0.05	s	
k =	2.25E-03	--	
v_x_init =	277.70	m/s	
v_y_init =	277.70	m/s	
max range =	1114.01	m	
time @ max range =	36.60	s	
max height =	623.03	m	
range @ max height =	812.76	m	
time @ max height =	13.15	s	

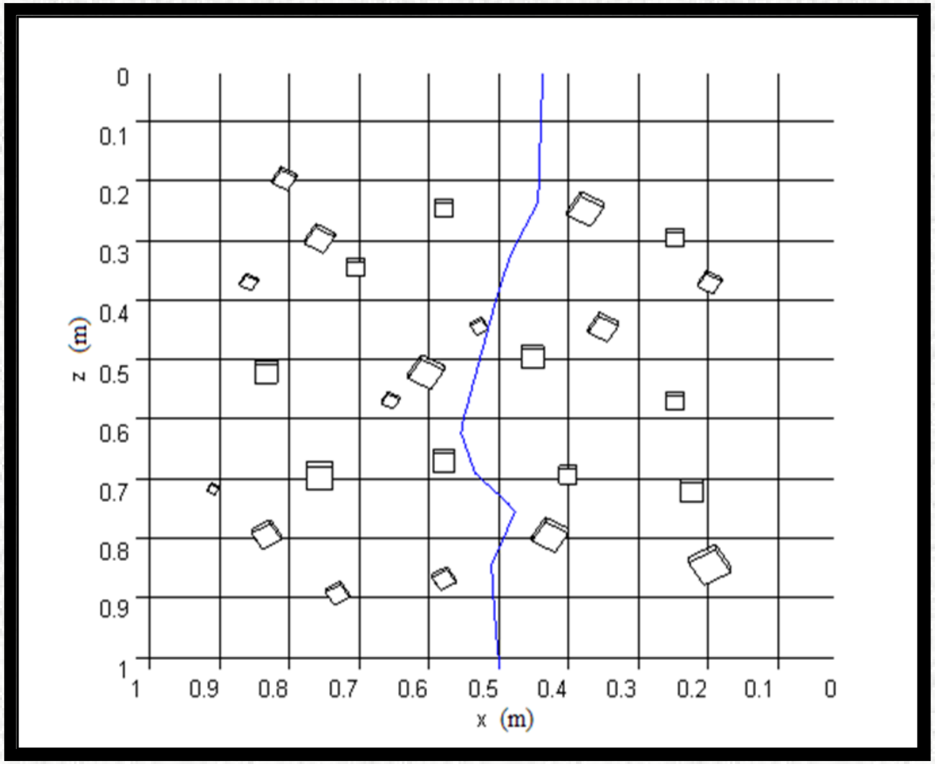
time	v_x	v_y	v	x	y
0.00	277.7	277.7	392.72705	0	0
0.05	265.4061	265.2206	375.20981	13.57765	13.57301
0.10	254.1806	253.8175	359.20902	26.56732	26.54897
0.15	243.8884	243.3545	344.53294	39.01905	38.97827
0.20	234.4164	233.7177	331.02115	50.97667	50.90507
0.25	225.6693	224.8112	318.53836	62.47881	62.36829
0.30	217.5661	216.5533	306.96964	73.5597	73.4024
0.35	210.0377	208.8744	296.21669	84.24979	84.03809
0.40	203.0243	201.7144	286.19494	94.57634	94.30281

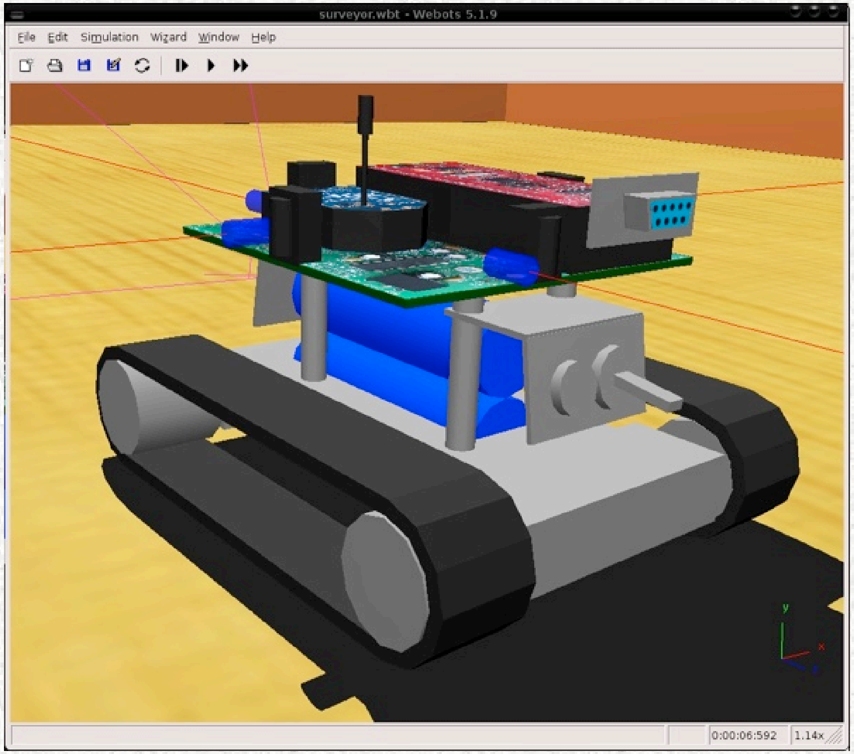


Assumptions: No wave drag
k value chosen based on spherical geometry

Where do we go from here?

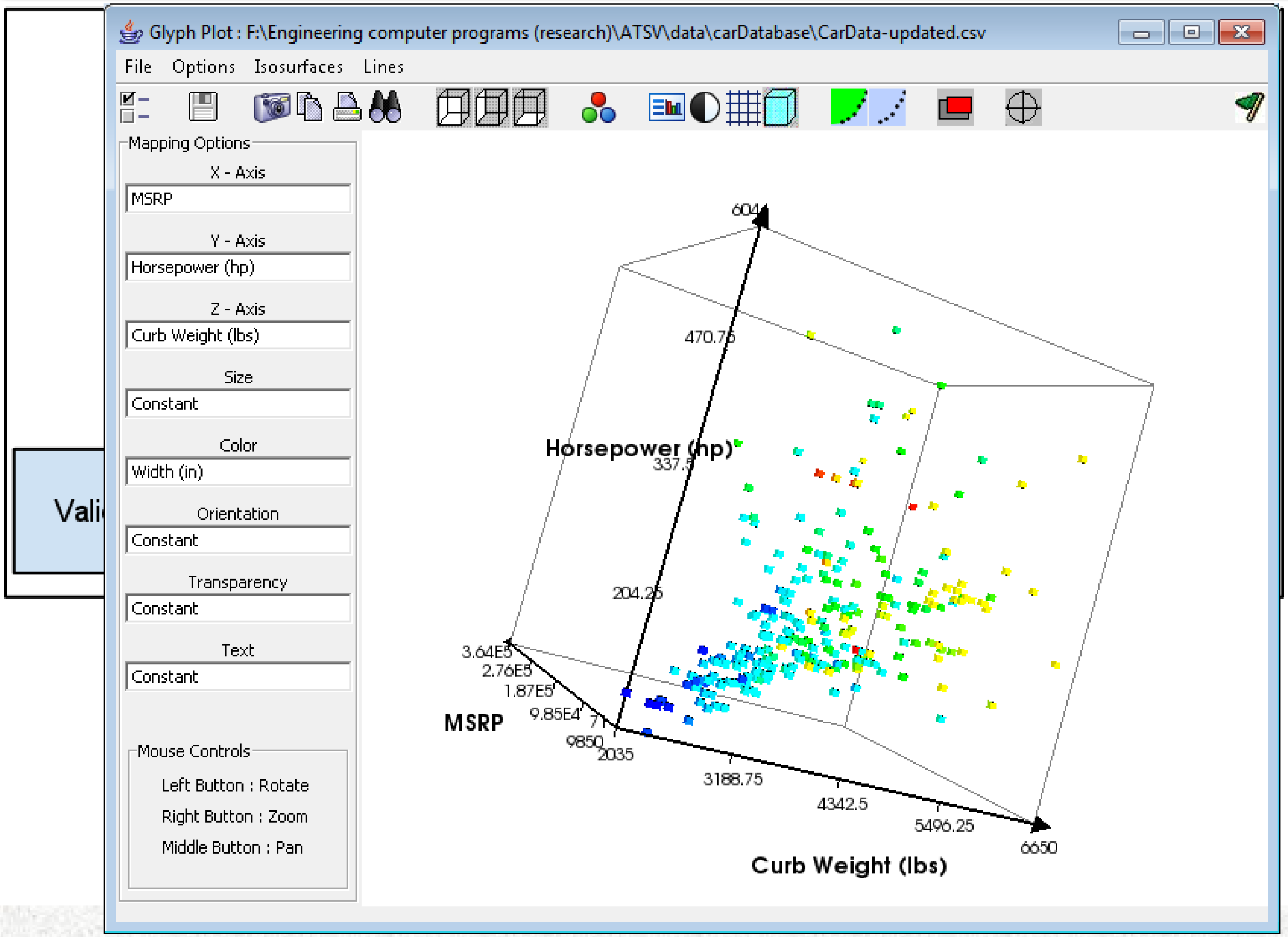
- Advanced simulations
  - Webots simulation software





Where do we go from here?

- Tradespace exploration



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